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MASTER OF MILITARY STUDIES

Location, Suppression, and Destruction of Enemy Air Defenses: Linking Missions to Realize Advanced Capabilities

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Executive Summary

Title: Location, Suppression, and Destruction of Enemy Air Defenses: Linking Missions to Realize Advanced Capabilities

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Thesis: The Suppression of Enemy Air Defense (SEAD) mission has evolved into a holistic approach that links kinetic and non-kinetic capabilities to attack enemy Integrated Air Defense Systems (IADS) as a whole. With increasing requirements placed on advanced multi-role SEAD aircraft, emerging aircraft such as the EA-18G must incorporate multiple mission capabilities with an adequately complex training infrastructure to realize their maximum capabilities.

Discussion: Air operations confronted the opposition of ground based defenses soon after the first aircraft arrived in the battlespace. As a result, enemy air defenses are not a new concept for air power. U.S. SEAD aircraft trace the history of their mission from five major benchmarks in history. In each of these benchmarks in the history of air power, an enemy IADS played a key opposing role. The lessons learned from these conflicts shaped the evolution of missions and associated aircraft. Air defenses were first integrated with radar, command, and control during World War II. In response, air forces made their first major technological advances in air defense suppression. During Vietnam, single-role aircraft employed piecemeal and target based suppression tactics that did not attack the enemy IADS as a whole system. SEAD as a dedicated mission and its associated technology evolved rapidly after Vietnam. Consequently, dedicated SEAD operations successfully employed a holistic approach to attack the Iraqi IADS during *Operation Desert Storm*. During *Operation Allied Force*, Serbian IADS adapted their own lessons learned and highlighted significant problems and limitations in U.S and NATO employment of SEAD assets. IADS technology and equipment is continuously improving and proliferating. Joint service air defense suppression capabilities are diminishing. SEAD capabilities should not deteriorate for lack of vision towards future threats. The EA-18G has the potential to meet the future threats in a holistic manner by combining advanced location, suppression, and destruction capabilities into a single weapon system. Contemporary and emerging SEAD aircraft, including the EA-18G, must employ multiple capabilities to meet the requirements of joint services. Advanced aircraft technology and missions create increased complexity within the cockpit. Advanced SEAD aircraft require an appropriately complex training infrastructure to achieve maximum combat effectiveness.

Conclusion: Integrated Air Defense System technologies are constantly becoming more advanced and will continue to proliferate throughout developing areas of the world. Joint service SEAD capabilities are diminishing while demands to meet a wide spectrum of SEAD requirements are increasing. Current and future multi-role SEAD aircraft, including the EA-18G, must incorporate a holistic approach to mission employment through networked, non-kinetic, and kinetic means. SEAD training environments must reflect the most advanced and complex IADS possible to enable aircrews to realize the maximum capabilities of the aircraft.

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Preface

Although the historical underpinnings of Suppression of Enemy Air Defense (SEAD) are as long-standing as airpower itself, the concept has only recently come of age and is often misunderstood. Moreover, the technological nature of the electromagnetic spectrum, computers, and air defense systems ensures that SEAD will remain a rapidly evolving element of airpower. Interest for this study was sparked by a renewed curiosity in history and the evolution of SEAD, their uniquely complex mission, and the generational leap currently being taken in a transformation of the U.S. Navy's carrier-based SEAD aircraft.

The study is approached in two parts. First, the evolution of SEAD aircraft and their mission is revealed through lessons learned over five major benchmarks in which an enemy Integrated Air Defense System (IADS) played a key role: World War II, Vietnam, *Operation Desert Storm*, and *Operation Allied Force*. *Operations Enduring Freedom* and *Iraqi Freedom* were omitted for lack of a "control group" IADS with which to draw conclusions. In the case of *Iraqi Freedom*, enemy air defenses had been significantly degraded and/or destroyed over ten years of combat response options exercised while enforcing Iraq's "no fly zone." Similarly, operations in Afghanistan involved less than rudimentary enemy air defenses. In both cases, SEAD aircraft continue to fly non-traditional missions that exceed both the scope and the classification of this paper. The second part of the study utilizes the benefit of hindsight to address implications for the future of SEAD aircraft. Special consideration is given to the proliferation of sophisticated threat systems amid declining SEAD assets, a modern approach to the SEAD mission, and emerging SEAD aircraft capabilities without an appropriately complex training infrastructure.

Within the context of current operations, where traditional U.S. Air Force, Navy, and Marine Corps SEAD aircraft have adapted their missions to enable direct support of ground troops through non-traditional methods, the topic of this study is not entirely in vogue. Nonetheless, joint force capabilities must not be allowed to deteriorate for lack of vision towards future threats. With the future threat in mind, the U.S. Navy will begin replacement of its carrier-based EA-6B this year by fielding a new aircraft, the EA-18G. Although Marine Corps EA-6B aircraft are not included in this plan, the transformation presents capabilities never before seen in the SEAD community. However, in my experience, training is an often overlooked stepchild of capability. The intent of this research is not to sprout unrealistic training goals but to promote further discussion and thought within a rapidly changing SEAD community.

In writing and researching this paper I have been helped and encouraged by several people. I am indebted to Lieutenant Michael Lisa, USN, a test pilot from the U.S. Navy's Air Test and Evaluation Squadron at Patuxent River Naval Air Station. LT Lisa's insight into complexity in the cockpit and the need for complex training for maximum EA-18G combat effectiveness formed the ideas for a significant portion of this paper. His ideas remain an area that should continue to be further developed for the EA-18G community. I also thank Captain Paul Overstreet, USN, Lieutenant Commander Paul Jennings, USN, as well as my friends and family for their support, and especially Doctor Donald Bittner for his mentorship in research and writing.

PART I: HISTORIC EVOLUTION OF SEAD AIRCRAFT

"War is both timeless and ever changing. While the basic nature of war is constant, the means and methods we use evolve continuously."
General A.M. Gray, USMC[1]

Ground based air defenses appeared as a threat to aviation immediately after humans first took to the skies. When the first combat aircraft fell to ground fire during the Italo-Turkish War of 1912, the threat to aircraft from ground based defenses became a factor that will endure as long as aircraft fly in combat.[2] As ground based air defenses evolved, countermeasures were required to mitigate these threats. Furthermore, continuous technological advances throughout history have mandated that air forces design specialized aircraft to accomplish the task of finding and suppressing air defenses. *Suppression of Enemy Air Defenses (SEAD)* is defined as a mission that neutralizes, destroys, or temporarily degrades surface-based enemy air defenses by destructive and/or disruptive means.[3]

SEAD Aircraft from World War II to Vietnam

The first attempts at location, suppression, and destruction of enemy air defenses from airborne aircraft centered on the Royal Air Force's determination to defeat German radar during the summer of 1942. After their own success of integrating radar, communications, command centers, and air defenses into a total system during the Battle of Britain, the British adopted tactics to find and defeat similar German equipment. Wellington bombers equipped with radar detection equipment served the prerequisite mission to find the suspected radar sites.[4] But British researchers understood that radar geo-location was only a prerequisite to suppressing or destroying the threat. They quickly devised a device that, when installed in an aircraft, received transmissions from a German radar site, amplified them, and sent them back to it. The targeted radar would receive the retransmitted "echos" and incorrectly display multiple false aircraft

targets which would confuse the operator. The device, codenamed Moonshine, was installed in a small number of P-82 Defiant "turret fighter" aircraft.[5] These aircraft were the originating designs for electronic attack (EA) aircraft that would later become a key part of the SEAD mission. Nonetheless, after specifically designed aircraft completed the job of locating enemy air defenses, dedicated jamming aircraft only produced a temporary sanctuary of suppression. The final mission to destroy enemy air defenses was ultimately left to aircraft with iron bombs.

It should be noted that during the Korean War, air defenses were similar to those of World War II. Consequently, suppression capabilities did not significantly progress. The greatest threat came from anti-aircraft artillery (AAA) paired with radar-guided searchlights. Electronic countermeasures within the bombers provided self-defense against searchlight radars, but flak suppression was still ultimately left to attack aircraft such as the B-29.[6]

SEAD Aircraft in the Vietnam War

During the years leading up to the Vietnam War, the Soviet Union made significant advances in designing the first generation surface to air missile (SAM) system, called the SA-2.[7] Specialized reconnaissance aircraft were designed to collect electronic intelligence (ELINT) on the SA-2, its associated radar, and other Soviet early warning radars. For example, Air Force RB-47H and EB-47E aircraft carried specialized receivers, recorders, and electronic warfare officers (EWOs) to intercept the characteristic SA-2 radar signals and missile telemetry. Similarly, the U.S. Navy EC-121 conducted extensive operations in the Pacific, Atlantic, and Mediterranean oceans to find various air defense radars in the Soviet Union.[8]

The increased requirement for complicated aircraft and equipment designed to contend with air defense systems became evident in May 1960 when the Soviets downed a U-2 high-altitude reconnaissance plane flown by Francis Gary Powers.[9] Five years later, Soviet SA-2

batteries were photographed being constructed in North Vietnam. In July, an SA-2 claimed its first victim of the war by shooting down an Air Force F-4C Phantom. U.S. Air Force and Navy commanders were shocked into realizing that a poor and non-industrialized state could quickly create an integrated air defense system that aircrews were ill-prepared to defeat.[10] This inability to appreciate the implications of an integrated system was a symptom of slow and ineffective SIGINT support against the rapidly expanding enemy IADS.[11]

To counter the SA-2, fighter-bombers adopted tactics that attempted to physically outmaneuver the missile, a problematic prospect for any bomb-laden aircraft at medium to high altitude. Pilots also attempted to avoid the engagement envelope of the SAM threat by flying below 3,000 feet, a dangerous tactic that left the aircraft within the heart of a deadly AAA environment.[12] As a result, SAMs and AAA claimed 85% of the 2,317 fixed wing aircraft combat losses from 1962 to 1973.[13] (See Appendices A and B for aircraft losses)

Historian Alfred Price notes that there were several important lessons learned during the early operations with SAM systems. Most importantly, the SAMs were lethal to air operations at medium to high altitudes. They were also well coordinated with lower altitude AAA guns, thus producing a deadly combination. Even if aircrews temporarily outwitted the SAM site by flying underneath its radar coverage, they would have to contend with radar guided AAA fire. Second, SAM sites were well camouflaged and could be easily moved to different locations. Aircrews relied heavily on the means to locate the SAMs from a safe distance; however, once a missile site was found by reconnaissance aircraft and target information passed, its destruction was difficult because within a few hours it would be moved to a new site.[14] Nonetheless, fighter and bomber aircraft entering missile defended areas were accompanied by RB-66C and EA-3B ELINT aircraft that could merely broadcast warnings to the attacking aircraft when they received SA-2

signals.[15] Despite the capabilities to warn attacking aircrews of SA-2 activity, the rudimentary equipment of SIGINT aircraft did not allow aircrews to quickly geolocate the SAMs with significant accuracy or precision.

The F-100F Wild Weasel and its replacement, the F-105G Wild Weasel II, marked significant advancements in the lethality of air defense suppression. The Wild Weasel II carried an EWO to operate receiver equipment designed to direct the pilot towards enemy SAM radars. If the SAM radar was radiating, the EWO would use his receivers to determine the general direction of the threat, and the pilot could then launch the AGM-45 Shrike anti-radiation missile (ARM) at the targeted SAM. The Shrike would home in on the enemy radar signal without requiring the F-105G crew to directly overfly the SAM site.[16]

The suppression mission added a new element with the introduction of modern jamming aircraft. Various aircraft from different U.S. services were introduced to provide radar-jamming support to aircraft on the way to their targets. The Marines first provided jamming support with the EF-10B Skynight. The Navy offered the EKA-3B Skywarrior, EA-6A Intruder, and EA-6B Prowler. The U.S. Air Force EB-66 Destroyer was perhaps the most well-known jammer. The combined efforts of these aircraft provided critical suppression of enemy air defenses with high-powered jamming.

The rapid buildup of North Vietnam's air defenses was staggering. Defenses in 1964 were limited to a small number of acquisition radars, AAA pieces, and no aircraft. Three years later, North Vietnam possessed an estimated 7,000 to 10,000 AAA pieces, 200 SA-2 sites with thousands of missiles, and nearly 100 Russian MiG fighters.[17] Soviet military aid also included early warning and height-finding radars. Radar netted coverage, a communications architecture, and a centralized command structure helped the SAM systems find targets and force them into

the radar guided AAA fire. They also provided the air-to-air fighters with a capability to communicate a ground-controlled intercept (GCI) of incoming attack aircraft. The synergistic effect of all these operations was to create an integrated air defense system (IADS).

The aircraft and SEAD tactics of the time were still in early development. SAM and AAA defenses were attacked in a piecemeal fashion, as a defensive measure to protect aircraft whose targets were located in heavily defended areas.[18] An IADS, however, is a combination of coordinated defenses with shared information from various sources. Pin-prick attacks do not necessarily destroy the whole. Eventually, tactics began to combine the capabilities of various aircraft against the IADS. This included SIGINT, jamming, and ARM carrying aircraft combined with the attack aircraft that they protected. To that end, anti-radiation missiles were eventually carried by regular attack aircraft and paired with Wild Weasels conducting "hunter-killer" missions. These missions, called "Iron Hand", used the ARM launched in a preemptive mode ahead of large strike packages destined to targets in well defended areas.[19]

Although Shrike and its follow-on, Standard ARM, appeared to be an extremely lethal weapon against a SAM radar, their limitations produced only a temporary sanctuary of suppression. The Shrike, which entered service in 1966, had a maximum employment range of 12 miles. At longer ranges, the SAM operators could launch a missile, guide it to intercept of an aircraft, and turn off the SAM radar before the Shrike had reached its target, depriving the ARM of its homing signal. In other words, the Shrike needed a cooperative target. Although early anti-ARM techniques, such as turning off the SAM radar, effectively produced the desired effect of temporarily neutralizing a SAM radar, the SAM site would survive to fight another day. Furthermore, SAM radars hit by ARMs could be rebuilt relatively quickly. Since the ARM had a

small warhead, the destroyed radar antennaes were replaced quickly and the SAM site soon returned to operation.[20] (See Appendix C for a list of ARM types)

During the course of Vietnam, SA-2 (and later SA-3) attacks on air operations became less effective due to improved U.S. aircraft and tactics. Seven years after the first F-4 shootdown, during the large-scale air attacks of *Operation Linebacker II*, SA-2 sites launched 50 missiles to achieve a single kill.[21] Although cumbersome, multiple layers of receiver-laden intelligence aircraft, stand-off jamming aircraft, fighters with suppression weapons, and hard-kill ordnance proved their potential for success when paired with strike aircraft that attacked defended targets. However, the approach used by SEAD aircraft needed refining. Lieutenant Colonel James Burgess, USAF, stated that SEAD was not a defined mission during the Vietnam War. Instead, the aircraft of the time espoused "piecemeal tactics directed at single sites, one at a time," as a function of the target or individual mission. This narrow focus was "defensive and reactive" in nature, and did not attack elements of the air defense as part of a whole.[22]

SEAD Aircraft in Operation Desert Storm

The Iraqi IADS of 1990 was the most advanced ground based air defense in the third world. Defenses included thousands of fixed and mobile SAMs, nearly 10,000 AAA guns, and a large air force.[23] The defenses also boasted technologies from around the world. They included Chinese low-frequency radars, capable of detecting stealth aircraft, Japanese passive detection systems, modern French and Italian low altitude radars, Russian early warning and height finding radars, and hundreds of observation posts. The heart of the IADS was a French computer system called Kari.[24] Kari fused tracking information from hundreds of observation posts and over 70 radar reporting stations, which in turn fed Intercept Operations Centers (IOCs) located throughout the country. Air defense officers inside the IOCs saw the fused information and

could pass targeting data to local SAM and AAA batteries and fighters. Using a hub and spoke design tied together with buried land lines, wireless communications, and telephones, the IOCs led to four regional Sector Operations Centers (SOCs) that orchestrated the overall defense of large areas of the country. At the center of the network was the National Air Defense Operations Center, headquartered in the heavily defended city of Baghdad, which provided Iraqi leadership with national level situational awareness of the air picture.[25]

The implication of such an integrated system is its inherent level of self-protection. An autonomous SAM must operate its radars to acquire and shoot targets; however, the longer these radars emit their energy, the more likely they will be targeted with anti-radiation missiles. The Kari system could pass targeting information gained through various sources that were not necessarily co-located with the SAM site it commanded. This minimized the time SAM operators used their radars and maximized their ability to avoid destruction.[26]

Coalition air planners understood that the piecemeal, target based SEAD tactics of Vietnam were an insufficient strategy for the Iraqi IADS. A *holistic approach* to employing SEAD aircraft and weapons was evident in the first three phases of *Desert Storm*. The first goal was to gain air superiority, then suppress enemy air defenses, and finally, continue pressure on these targets while shifting the emphasis to the field army.[27] Instead of target based or single-site suppression methods, SEAD missions had five objectives that attacked the IADS *as a whole*:

1. Destroy/disrupt command and control (C2) nodes
2. Disrupt EW/GCI coverage and communications
3. Force air defense assets into autonomous modes
4. Use expendable drones for deception
5. Employ maximum use of high-speed ARM (HARM) shooters[28]

The capability to identify and locate pieces of the IADS puzzle was robust. RC-135 Rivet Joint and EP-3 Aries signals intelligence (SIGINT) aircraft orbited at safe distances from

the battlespace to intercept, identify, and locate radar emissions and communications from the IADS structure. This type of intelligence was crucial to SEAD planners, but required time within the planning cycle to collect, analyze, and redistribute useable information regarding the status of the Iraqi IADS.[29]

The individual SEAD aircraft and weapons that would achieve these objectives had also advanced significantly since the Vietnam War. Specifically, the U.S. Air Force had developed the F-4G Advanced Wild Weasel, the EF-111A Raven, and the EC-130H Compass Call. The F-4G was an advanced version of its Vietnam era predecessor, the F-105G. The EF-111A was a radar jamming aircraft that used the same equipment as the Navy EA-6B. The EC-130H jammed the enemy's command and control communications. Although the EA-6B and F-4G possessed the capability to fire the most current ARM upgrade, the High Speed Anti Radiation Missile (HARM), the ultimate destruction of key IADS targets was ultimately left to attack aircraft of the day. F-117A bombers targeted key C2 and IADS structures in Baghdad, leaving other IADS targets for aircraft such as the F-15E, F-111, A-6, F/A-18, B-52, and British Tornado GR1.[30]

In *Desert Storm's* first attacks, all SEAD assets had the intelligence of the IADS structure and locations provided by SIGINT aircraft. Second, unmanned drones flew into defended areas to stimulate the SAM batteries to fire their missiles. Third, EF-111A and EA-6B jammers neutralized early warning and acquisition radars in order to deny SAMs the situational awareness of the Kari system. This forced them to rely on their pencil-beam tracking radars to find the drones. Fourth, strike packages consisting of the EA-6B, along with F-4G, F/A-18, and A-7 aircraft, attacked the radiating SAM sites with HARMs. Finally, F-117A attacks targeted the most heavily defended operation centers and key C2 nodes, along with Tomahawk Land Attack

Missile (TLAM) attacks from Navy ships and long range Air Launched Cruise Missile (ALCM) attacks from distant B-52 bombers.[31]

Operation Desert Storm employed a wide array of aircraft, each with distinctive capabilities; however, in contrast to the piecemeal tactics of Vietnam, the aircraft of *Desert Storm* utilized a holistic approach. This approach to SEAD combined unique capabilities of several aircraft in a coordinated fashion to neutralize the entire Iraqi IADS as a whole.

SEAD Aircraft in Operation Allied Force

Dr. Benjamin Lambeth states that, "in contrast to the far more satisfying SEAD experience in *Desert Storm*, the initial effort to suppress Serb air defenses in *Allied Force* did not go nearly as well as expected."[32] Yugoslavia presented a greater challenge to air planners due to its mountainous topography, prohibitive weather, and a modern IADS run by well trained operators who had honed their skills over years of practice. *Allied Force* planners estimated that as many as ten aircraft could be lost in the initial strikes due to the robust Yugoslav IADS.[33]

A well networked radar system allowed the Serbs to keep their SAMs constantly moving and dispersed from known garrisons, with tight emission controls over SAM target tracking radars to avoid becoming cooperative targets for NATO aircraft.[34] Low altitude defenses included the "killing zone" of AAA pieces, but added significant man-portable air defenses that tied into the radar network and restricted Allied aircraft to remain above 15,000 feet.[35]

Due to the retirement of the Air Force F-4G and EF-111A aircraft, the SEAD plan for Allied Force relied on only 48 U.S. Air Force F-16CJs and 30 Navy and Marine Corps EA-6Bs. The low numbers of available EA-6B Prowlers, the only tactical electronic attack aircraft in the U.S. inventory, raised concerns over the pressures of low density, high demand (LD/HD) assets. The EC-130H was used to tackle voice communications of the IADS and opposing fighters.

RC-135 and U-2 flights attempted geolocation of mobile SA-6 vehicles, as well as SA-2 and SA-3 sites that had been moved from their garrisons.[36]

One of the major problems with SEAD aircraft capabilities was exposed as a result of the enemy's limited activation of SAM target tracking radars until absolutely necessary during an engagement. These emission control tactics made Serbian SAMs difficult to locate and increased their survivability. The tactics in turn denied NATO aircraft the ability to destroy high-risk targets and increased the overall requirements for SEAD aircraft sorties.[37]

The difficulty in targeting non-cooperative SAMs for kinetic suppression was compounded by challenges in threat geolocation. ELINT collecting aircraft and assets could not efficiently track SAM batteries that used targeting data obtained from radars at distant locations.[38] Moreover, the excessive time involved in the turnaround of information from intelligence, surveillance, and reconnaissance (ISR) assets to shooters was not fast enough to catch briefly emitting radars before they moved to new locations. In some cases it took "a matter of days" to get that information to aircrews flying the bombing missions.[39] A lack of real-time SAM radar geolocation data was a significant problem for the use of HARM in the reactive role, a common tactic of the F-16CJ.[40] Despite over 740 HARMs fired by EA-6B, F-16CJ, and other aircraft, only three of Serbia's twenty five known mobile SA-6 batteries were confirmed destroyed by the final week of operations. Consequently, Allied aircraft remained within the engagement envelope of Serb SAMs throughout the conflict. An enemy SA-3 downed an F-117A and damaged another, which marked the first combat casualties of stealth aircraft. Additionally, one F-16 was lost and four other aircraft sustained damage from air defenses.[41] (See Appendix D for loss rates compared to SEAD sorties expended).

A second relevant deficiency of SEAD aircraft appeared in *Allied Force*: the lack of stand-off weapons utilized to destroy enemy air defenses. If intelligence permitted, DEAD attacks employed strike aircraft that carried precision guided munitions (PGMs) to achieve permanent IADS kills. Mobile and unlocated SAMs create more than just a targeting problem for precision weapons; in addition, aircraft must operate at greater distances from the general areas in which unknown threats may exist to accept the same level of risk. However, stand-off weapons were used infrequently against IADS targets in *Allied Force*.[42] (See Appendix E for a list of SEAD stand-off weapons)

Although air power was an overall success in *Allied Force*, NATO never fully succeeded in neutralizing the Serb IADS. Moreover, Lambeth concluded that by remaining dispersed, mobile, and selective with radar emissions, "Serb IADS operators yielded the short term tactical initiative in order to present a longer term operational and strategic challenge to allied combat sorties."[43] In the end, historians identified significant areas for improvement needed by SEAD aircraft, including timely geolocation and targeting of air defenses with longer range weapons.

The evolutionary lessons of SEAD aircraft since World War II show that U.S. air forces expanded their capabilities across a wide spectrum of SEAD operations. However, no aircraft to date has completely fused multiple aspects of SEAD/DEAD in a way that significantly enhances air power. To do so requires the fusion of precise ISR, electronic attack, suppression weapons, and hard kill weapons within a single aircraft's weapons system. *The combination of these capabilities* further needs to be linked to a network of off-board sensors. By fusing information from off-board sensors with its own, an aircraft can provide an extremely accurate and precise awareness of the battlespace. Furthermore, one that also shares this real-time intelligence with other platforms in theater through datalink networks can reduce the "fog of war."

PART II: IMPLICATIONS FOR THE FUTURE

"Only the wisest and stupidest of men never change"
Confucius[44]

In today's complex global environment, a popular perspective among military professionals is that future adversaries will adopt "unorthodox strategies and tactics" to asymmetrically challenge the conventional warfighting capabilities of the United States.[45] Irregular warfare and asymmetric approaches are common terms in the modern military context. However, the term "asymmetric" does not necessarily mean "without technology."[46] In consideration of the U.S. dominance in air operations, enemy technologies are likely to include air defense radars, SAMs, and AAA because these systems continue to proliferate the arms market. A 2006 Congressional research report shows that developing nations (where high potential for regional conflicts exist) seek significant arms transfers. The developing world is a primary focus for foreign arms sales activity and accounts for nearly 70% of all arms transfer agreements made worldwide.[47] Finally, the African arms market is showing signs of growth, to include modern air defense systems, communications networks, and fighter aircraft.[48]

The types of arms being spread throughout the developing world also indicate the future of advanced enemy air defenses. According to Ruslan Pukhov, head of Moscow's Center for Analysis of Strategies and Technologies, air defense weapons account for 15% of the worldwide weaponry market.[49] In 2005 alone, Iran purchased twenty-nine SA-15 SAM systems and India purchased twenty-four SA-19 systems.[50] Russia exported its highly advanced SA-10 to China, Cyprus, Iran, Kazakhstan, Syria, Belarus, Bulgaria, Croatia, Greece, Hungary, India, and Vietnam.[51] These "double digit" SAMs are a concern due to their "mobility, long range, high altitude, advanced missile guidance, and sensitive radars," and their capability to disrupt U.S. air operations from great distances.[52] China's indigenous defense industry primarily produces short-

range SAM systems, but is attempting to design more modern and capable systems for its naval vessels.[53] Similar reports suggest that China will purchase the Russian SA-20, an extended-range version of the SA-10.[54] As arms makers continue to proliferate air defense systems, air planners can expect their use throughout areas in which U.S. forces conduct operations. Furthermore, it must be assumed that enemy state actors of the future will draw on lessons learned from U.S. airpower in *Desert Storm* and *Allied Force*. Thus, U.S. advances in SEAD must span a wide spectrum of synergistic capabilities in geolocation of enemy air defenses, non-kinetic and kinetic suppression methods, and destruction from stand-off distances.

Required Improvements for SEAD Aircraft

The evolutionary lessons of air operations since World War II show that U.S. air forces require ever-increasing capabilities. Even before the taxing military operations of the post-9/11 era, the U.S. Joint Chiefs of Staff found that joint service suppression capabilities were diminishing while the proliferation and modernization of enemy air defenses were increasing.[55] Therefore, attempts to defeat an IADS must consider a holistic approach that combines an array of aircraft capabilities. SEAD aircraft require accurate, precise, and real-time intelligence on the IADS structure and the ability to share it with other platforms. Additionally, SEAD aircraft need enhanced capabilities in time sensitive targeting of fleeting air defenses from greater range. Most importantly, as aircraft become capable of performing these functions, their aircrews must train sufficiently in complex environments that accurately represent *five areas of concern: non-cooperative IADS, time-sensitive targeting, high demand environments, and holistic SEAD.*

Non-cooperative Integrated Air Defense Systems

In 2000, Lieutenant General Marvin Esmond, USAF, reported to Congress that the term "non-cooperative" describes an IADS that is not acting in the traditional manner, or one that uses

more modern SAMs. The U.S. experience in *Allied Force* confirmed that future adversaries will continue to adopt irregular, non-cooperative methods to counter U.S. SEAD efforts.[56] Non-cooperative air defenses create a challenge for antiquated ISR and geolocation systems in the current U.S. inventory. These older systems require time to analyze and process radar emissions. Real-time reconnaissance of SIGINT data must be an efficient process that is capable of producing accurate and precise location data in a matter minutes from fleeting radar emissions. Non-cooperative radars also have a crippling effect on HARM tactics, both for reactive shots used by the F-16CJ and in the preemptive mode normally used by the EA-6B.

In recognition of these shortfalls, the U.S. Navy is introducing the Advanced Anti Radiation Guided Missile (AARGM) in 2009. The AARGM upgrades the existing HARM to a precision weapon that is more effective against non-cooperative air defense systems. Depending on its availability and test schedule, the AARGM will be integrated on the Italian Tornado and U.S. Navy F/A-18C/D/E/F and EA-18G aircraft.[57]

Sensor-to-Shooter Delays in Time Sensitive Targeting

Airborne reconnaissance of SIGINT data must be an efficient process that can be translated into actionable targeting data and immediately disseminated to strike aircraft cockpits. Therefore, precision engagement of mobile, non-cooperative targets requires a shortened "sensor-to-shooter" kill chain that demands real-time ISR and real-time targeting.[58] The majority of SIGINT specific ISR data comes from a wide variety of airborne sensors, manned and unmanned, that operate at safe stand-off distances from ground threats. However, a tactical aircraft that combines advanced SIGINT collection, geolocation, and datalink dissemination capabilities could generate real-time data from "within the battlespace" and improve the real-time intelligence data that stand-off ISR assets produce. This would also reduce delays in the

sensor-to-shooter timeline for the assortment of other aircraft that access the datalink information.[59]

Low Density, High Demand Environments

The Department of Defense considers certain key military capabilities as "low density, high demand" (LD/HD). These assets, including the EA-6B, are defined as "force elements consisting of major platforms, weapons systems, units, and/or personnel that posses unique mission capabilities and are in continual high demand to support worldwide joint military operations."[60] Airborne electronic attack is a unique capability that will remain in considerable demand as weapons proliferate.[61]

Low-observable, or "stealth" aircraft, do not reduce the requirement for airborne electronic attack or LD/HD aircraft. The F-117A shootdown during *Allied Force* is a reminder that low-observable aircraft have limitations. As Air Force General Richard Hawley commented, "when you have a lot of unlocated threats, you are at risk even in a stealth airplane."[62] As Lambeth explains, low-observable aircraft have a significantly enhanced survivability against an IADS because the enemy's window of opportunity is narrowed; however, one cannot operate stealth platforms with complete disregard to enemy defenses.[63] Additionally, stealth aircraft are considered force multipliers for U.S. airpower in high threat environments; however, these aircraft represent a small percentage of U.S. air power.[64] Experts agree that non-stealthy "legacy" aircraft and stealthy planes alike will continue to require support from electronic attack aircraft for joint operations in a threat environment.[65]

Since the retirement of the U.S. Air Force EF-111A in 1998, the Navy and Marine Corps EA-6B remains the only dedicated electronic attack aircraft available to U.S. and NATO air power.[66] Beginning in 2008, the aging U.S. Navy EA-6B fleet will be phased out and replaced

with its follow on aircraft, the EA-18G Growler Airborne Electronic Attack (AEA) aircraft (See Appendix F). Ninety EA-18Gs will replace the Navy's 10 carrier based EA-6B squadrons and fulfill the requirements for training and test aircraft; however, the Navy will also gradually disestablish all its expeditionary EA-6B squadrons which also provide significant AEA for the U.S. Air Force.[67] Additionally, the U.S. Marine Corps plans to begin retirement of the EA-6B in 2016.[68] Thus, the density of AEA and SEAD assets will diminish substantially over the next ten years. The implications of reducing available LD/HD SEAD aircraft are significant to the Navy EA-18G fleet. Increased demands require the aircraft to provide flexible options across a spectrum of potential service requests for advanced capabilities that include real-time network ISR, electronic attack, suppression weapons, and stand-off DEAD.

The Holistic Approach to SEAD

A holistic approach to SEAD combines sensor and datalink technologies to build a suppression network in which manned and unmanned ISR or EW aircraft, suppression aircraft, command and control aircraft, and strike aircraft are interconnected in real-time.[69] The combination of SEAD capabilities destroys the IADS as a whole through appropriate objectives. For the individual aircraft, the holistic approach must also mix advanced ISR capabilities with electronic attack, ARM weapons, and stand-off precision-guided weapons. This approach is consistent with the joint analysis of alternatives for the AEA mission which the Department of Defense (DoD) initiated in 1999. The design of the EA-18G is a result of the study.[70]

Rear Admiral Mark Fitzgerald, Deputy Chief of Naval Operations, stated in March 2004 that, "the Navy and Marine Corps' continued success in providing long-range precision strike is due to determined investment in flexible, multi-role platforms with ever-improving capabilities."[71] The terms "flexible" and "multi-role" also apply to holistic SEAD. Navy SEAD

must encompass capabilities previously carried within the weapon systems of multiple separate aircraft. Additionally, the capabilities that are required are continually becoming more advanced. Therefore, the EA-18G must also employ a holistic, multi-role approach to SEAD to attack a modern IADS. The EA-6B employs an array of SEAD capabilities, including EA of early warning, acquisition, fire-control radars, communications, and use of the HARM. The EA-18G will add real-time ISR with its precision geolocation capability; however, it must come "full circle" and add stand-off weapons to its arsenal. This planned, yet unfunded, necessity creates a spectrum of capabilities not previously seen in SEAD aircraft (See Appendix G). It also supports not only Navy SEAD requirements, but is in accordance with a joint approach to improve capabilities throughout the services against a spectrum of enemy electronic capabilities.

Complex SEAD Training Against a Modern Adversary

Lieutenant Colonel James Brungess, USAF, among others, stated that multi-role applications of aircraft have enormous implications on training systems and infrastructures. Since aircraft have multiple missions, aircrews must train to all of them.[72] Additionally, aircraft involved in the SEAD mission, by definition, *must train in a coordinated manner with the aircraft which they "protect"* as well as against their ground-based air defense adversary. This coordination entails a significant level of *complexity to the training infrastructure* required by any SEAD aircraft. The real-time geolocation capabilities of modern SIGINT assets also warrant a modern, dynamic, and threat-dense environment to act as their adversary IADS in training. The advent of MIDS networks and real-time coordination and integration has added yet another level of complexity to the SEAD mission. Thus, the *training infrastructure available to the aircraft involved must be similarly complex.* The EA-18G incorporates major advances in all of the aforementioned areas. Therefore, the implementation of an appropriately complex training

system is especially important for future EA-18G squadrons. Otherwise, an illusion of capability exists in an aircraft that aircrew are not capable of fully employing.

Although the *major training complexes* commonly used by Navy, USAF, and USMC air forces provide some of the most tactically advanced combat training in the world, they are in *need of significant transformation to properly address the training requirements of next-generation SEAD aircraft*. For carrier airwings soon to employ the EA-18G, the Naval Strike and Air Warfare Center (NSAWC) Fallon Range Training Complex is in need of modern enemy radars (real or simulated), mobile SAM systems, and IADS targets that replicate the most dangerous threats anticipated.[73] The Nellis Air Force Base Nevada Test and Training Range also does not represent the latest generation IADS. Additionally, training ranges lack sufficient assessment systems that provide analysis of holistic SEAD attacks on the entire IADS.[74] Finally, unlike other U.S. Navy aircraft weapons schools, the Whidbey Island Naval Air Station's Electronic Attack Weapons School is not co-located with NSAWC and owns no aircraft. This problem will limit the proficiency and expertise of future EA-18G tactics instructors, since the EA-18G and EAWS base location lacks sufficient IADS training ranges or simulator systems. All of these factors could lead to a situation in which the full capabilities of the aircraft are not fully realized due to training shortfalls.

Complexity Within the Cockpit

A holistic approach to SEAD in a complex threat environment also places increased demands on the individual multi-role SEAD aircraft. When managing a variety of sensors and weapon systems in this environment, the aircrews' primary job is to "balance workload across time in a multi-tasking environment."[75] For the two-person EA-18G, the number of sensors that provide actionable information for the aircrew to process is much higher than other SEAD

aircraft. This includes the MIDS network, ALQ-218(V2) receivers, satellite communications, AESA radar (air and ground), CCS receivers, and radio communications. Additionally, aircrew tasks are increased due to the various weapons systems and missions available to the EA-18G crew, in addition to basic flight tasks. These factors result in complexity levels that exceed those achieved in current SEAD training sorties.[76]

Risk in this area is mitigated by automation within cockpit systems and displays; however, studies have shown that cockpit automation can paradoxically become a "mind-suck" to the aircrew whose high workload distracts them from other basic flight tasks. Consequently, there is potential to underestimate the training requirements of highly complex and automated cockpits.[77] To train an EA-18G aircrew is to train in a highly complicated environment.

In consideration of the apparent shortfalls in SEAD training, the financial costs associated with their transformation, and the need to train in an operationally realistic and complex cockpit environment, *a growing area of interest is in high fidelity simulators*. Although mission simulators *are not a replacement for flight hours*, they do provide worthwhile mission training. A properly designed aircraft simulator can serve not only as a synthetic flight trainer, but can train aircrews in complex mission skills that are difficult or impossible to gain in the actual aircraft. However, the simulator must be capable of training and assessing the cognitive behavior of aircrews in fusing information from multiple sensors, making decisions, and solving problems related to a realistic and complex SEAD environment.[78] Furthermore, because of the need for SEAD aircraft to train with "protected entities," the synthetic SEAD environment should include Distributed Mission Operations (DMO) that link large numbers of dissimilar aircraft simulators from various sites across the country to "fly" in synthetic missions. Synthetic, theater-level exercises, known as "Virtual Flags," are now being coordinated by the U.S. Air

Force for joint participants in different locations.[79] The EA-18G fleet introduction team is advocating complex IADS simulation and DMO capabilities for the EA-18G simulator system.[80] Nonetheless, there are technical challenges that hinder efforts to generate a realistic IADS simulation in the EA-18G Tactical Operational Flight Trainer (TOFT).[81]

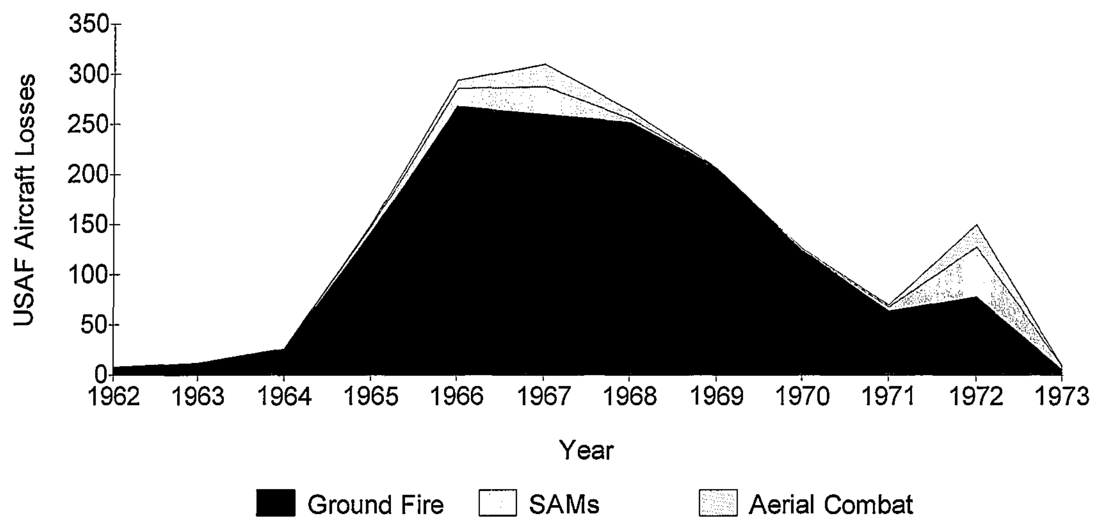
CONCLUSION

20th century history revealed a continuous development of enemy air defenses. Consequently, their airborne countermeasures also evolved. Advanced IADS will continue the trend of modernization. Furthermore, the proliferation of radar systems and advanced air defense systems warrants increased capabilities in SEAD. Although air defense proliferation proves the need for SEAD aircraft, the numbers of airborne electronic attack aircraft will decline in years to come. Therefore, SEAD aircraft must encompass a holistic and multi-role approach in both their design and their employment in support of joint service requirements.

The EA-18G combines technology and capabilities never before seen in the electronic attack community. The advanced, network-centric, precision geo-location systems inherent in the initial design have potential to be linked to multiple stand-off non-kinetic and kinetic weapons. If stand-off weapons are added to the EA-18G as planned, the DoD's next generation SEAD aircraft will combine precise geolocation, suppression, and destruction of enemy air defenses like never before. *Nonetheless, with advanced technology comes increased complexity in the cockpit, and the requirement for a similarly matched training infrastructure*. The inherent requirement in SEAD training is for coordinated flights with other aircraft against modern ground systems that can provide complex input (real or simulated) into the cockpit. The electronic attack training infrastructure must advance to match the enemy IADS of the future, in order for EA-18G aircrews to realize the full capabilities of the aircraft.

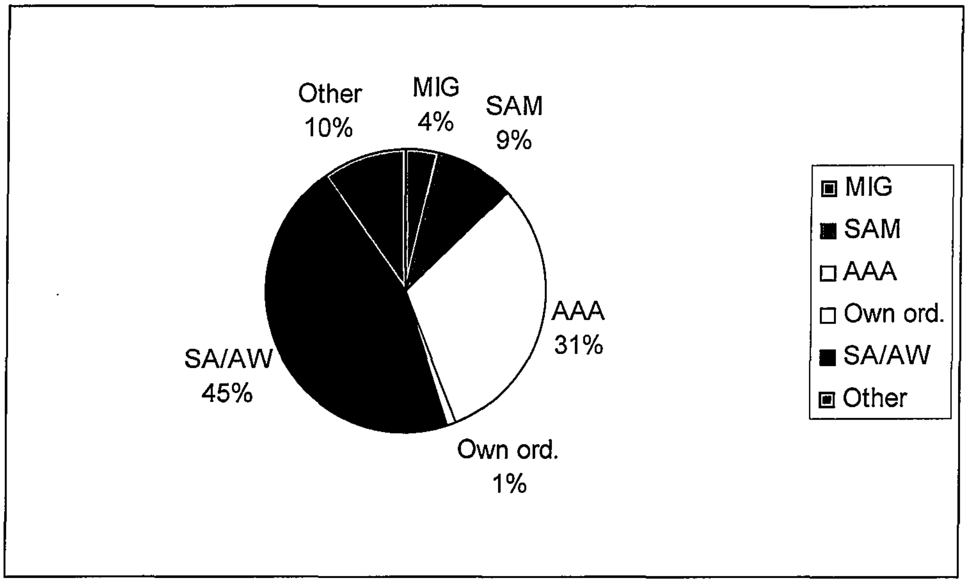
APPENDIX A - USAF Aircraft Combat Losses in Southeast Asia by Cause (Annual from 1962-1973)

Year	Ground Fire	Surface to Air Missiles	Aerial Combat
1962	7		
1963	12		
1964	25		
1965	142	5	3
1966	267	18	8
1967	260	28	22
1968	252	3	9
1969	206		
1970	124		1
1971	64	4	1
1972	78	49	23
1973	6	3	
Total	1443	110	67



Source: Wayne Thompson, *To Hanoi and Back: The United States Air Force and North Vietnam 1966-1973* (New York: University Press of the Pacific, 2005), 311.

APPENDIX B – Combined Services (Fixed Wing) Aircraft Combat Losses in Southeast Asia by Cause (January 1962 - June 1973)



MIG: enemy fighter aircraft
SAM: Surface to Air Missile
AAA: Anti Aircraft Artillery
Own Ordnance: Own ordnance fragmentation
SA/AW: Small Arms/Automatic Weapons
Other: Aircraft failure or unknown

Source: Michael McCrea, *U.S. Navy, Marine Corps, and Air Force Fixed Wing Aircraft Losses and Damage in Southeast Asia (1962-1973)* (Washington, D.C.: Center For Naval Analysis, 1976), section 1, page 13.

APPENDIX C – Relevant Anti Radiation Missiles (ARMs)

Anti radiation missiles have an unparalleled ability to home in on enemy radar emitters and disrupt or destroy the elements of an integrated air defense system (IADS). However, they are not considered precision-guided weapons, such as laser or GPS guided munitions (with the exception of the AARGM, detailed below). On the contrary, ARMs cannot be steered and under certain conditions may not guide on the target for which they were originally fired. Also, they do not have the ability to discern friend from foe. Therefore, the precision detection capability of the launching platform and its human operator in the loop are key elements ensuring weapon effectiveness and the prevention of fratricide. Current ARM weapons all depend on RF homing for guidance and are vulnerable to emission control (EMCON) countertactics; they require cooperative target radars to complete an engagement. There is also limited capability to perform real-time battle damage assessment.

AGM-45A Shrike - The Shrike was the first missile built specifically for the anti-radar mission, and more than 20,000 were produced beginning in 1962. Shrike's effectiveness was limited by the requirement for the missile to be pointed at the intended target radar during launch, and that the Shrike would lose its lock if the radar ceased to radiate.

AGM-78 Standard ARM - The Standard ARM was an improvement in the capability of the existing AGM-45A Shrike, and was used extensively during the Vietnam War. The missile could be launched from aircraft while operating at greater ranges from enemy air defenses than the Shrike. Successive improvements led to three more models with better seekers, electronic counter-countermeasures and increased range.

AGM-88 HARM - The High Speed Anti Radiation Missile is a supersonic missile designed to seek and destroy enemy radar-equipped air defense systems. The AGM-88 can detect, attack and destroy a target with minimum aircrew input. It has the capability of discriminating a single target from a number of emitters in the environment. A smokeless, solid-propellant rocket motor propels the missile. The USAF F-16CJ, German and Italian Tornado ECR, and the Navy and Marine Corps F/A-18 and EA-6B have the capability to employ the AGM-88.

AARGM – The U.S. Navy's Advanced Anti Radiation Guided Missile is a software and hardware upgrade to the AGM-88 that will incorporate a more sensitive receiver, GPS/INS to improve precision, and a millimeter wave (MMW) radar that actively searches the target's terminal area to destroy air defense units employing anti-ARM shutdown tactics. The AARGM can also receive real-time intelligence prior to launch and transmit a weapon impact assessment just prior to impact. AARGM transforms HARM into a precision DEAD weapon and is scheduled to enter service in 2009.

Source: Federation of American Scientists Military Analysis Network, "DoD 101 An Introduction to the Military: U.S. Missiles," http://www.fas.org/man/dod-101/sys/missile/index.html

APPENDIX D – Estimates of Combat Aircraft Losses and SEAD Effort Expended

Despite the deficiencies in SEAD capabilities that were exposed by Serbian IADS and the F-117A and F-16CJ shootdowns, aircraft losses were less than was expected during *Allied Force*. This is consistent with the decline of U.S. aircraft combat losses since World War II.

Estimates of Combat Aircraft Losses

Conflict	Combat Sorties	Total Combat Losses	Attrition Rate
World War II	2,498,283	19,030	0.762%
Korea	591,693	1,253	0.212%
Vietnam (USAF only)	219,407	1,443	0.658%
Desert Storm	68,150	33	0.048%
Bosnia	30,000	3	0.010%
Kosovo	21,111	2	0.009%
Northern/Southern Watch	268,000	0	0.000%
Iraqi Freedom (as of 2003)	20,733	1	0.005%

When considering the adoption of SEAD as a dedicated mission after Vietnam, it is clear that SEAD is a contributor to aircraft survivability. Furthermore, for recent conflicts in which an enemy IADS was present, 20-30% of all combat sorties were devoted to SEAD. Historically, this ratio was suddenly much higher in *Allied Force* than in *Desert Storm* or Vietnam. As Christopher Bolkcom stated, this suggests that "SEAD is a growing mission area." SEAD aircraft must continue to expand their capabilities.

Estimates of SEAD Effort Expended

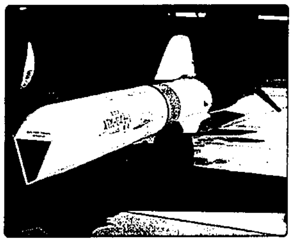
Conflict	Combat Sorties	SEAD Sorties	SEAD Effort
Vietnam (USAF only)*	219,407	11,389	5.2%
Desert Storm	68,150	7,244	10.6%
Bosnia	2,451	785	32.0%
Kosovo	21,111	4,538	21.5%
Northern/Southern Watch	268,000	67,000	25.0%

* It should be noted that SEAD was not a doctrinal mission during Vietnam. Furthermore, these numbers reflect F-105G and flack suppression sorties only.

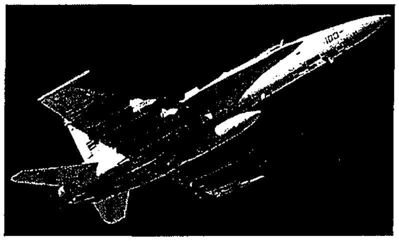
Source: Christopher Bolkcom, *Military Suppression of Enemy Air Defenses (SEAD): Assessing Future Needs* (Washington, D.C.: The Library of Congress, Congressional Research Service, 2005), 4-5.

APPENDIX E – Relevant Stand-off Weapons

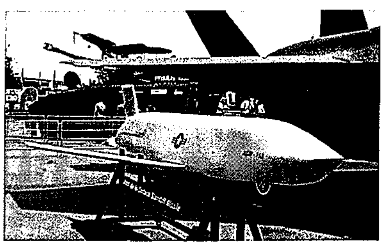
AGM-84 Stand-off Land Attack Missile Expanded Response (SLAM-ER) – The Standoff Land Attack Missile - Expanded Response (SLAM-ER), is a day/night, all-weather, over-the-horizon precision strike missile. Capable of hitting stationary or moving targets on land or at sea, SLAM-ER can be retargeted after launch via several man-in-the-loop features that enhance the accuracy of the weapon.



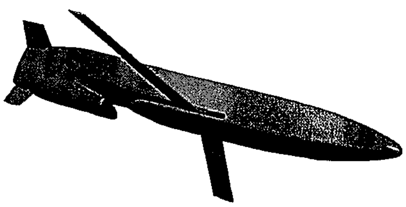
AGM-154 Joint Stand Off Weapon (JSOW) – JSOW is a kinematically efficient and un-powered glide weapon that provides standoff capabilities from up to 70 nautical miles. The JSOW can be used against a variety of land and sea targets and can operate from ranges beyond most enemy point defenses. JSOW's low radar cross section and infrared signature are stealth features and ensure a high probability of survival en route to heavily defended targets.



AGM-158 Joint Air to Surface Stand-off Missile (JASSM) - JASSM is a long range, precision cruise missile designed for launch from stand-off ranges to destroy high value, well-defended, fixed and mobile targets. After launch, it will be able to fly autonomously, without aircrew commands or datalink requirements, over a low-level circuitous route to the area of a target.



Medium Air Launched Decoy – Jammer (MALD-J) – Although MALD was not designed as a stand-off kinetic weapon, its purpose enables their use. MALD stimulates an enemy IADS by flying preprogrammed routes into defended areas and forces air defenses to attack the perceived air threat. This confuses the IADS and exposes the locations of non-cooperative SAMs and makes them vulnerable to attack. MALD-J incorporates an electronic attack payload to jam elements of the enemy IADS, and is currently undergoing testing.



Quoted from the following sources:

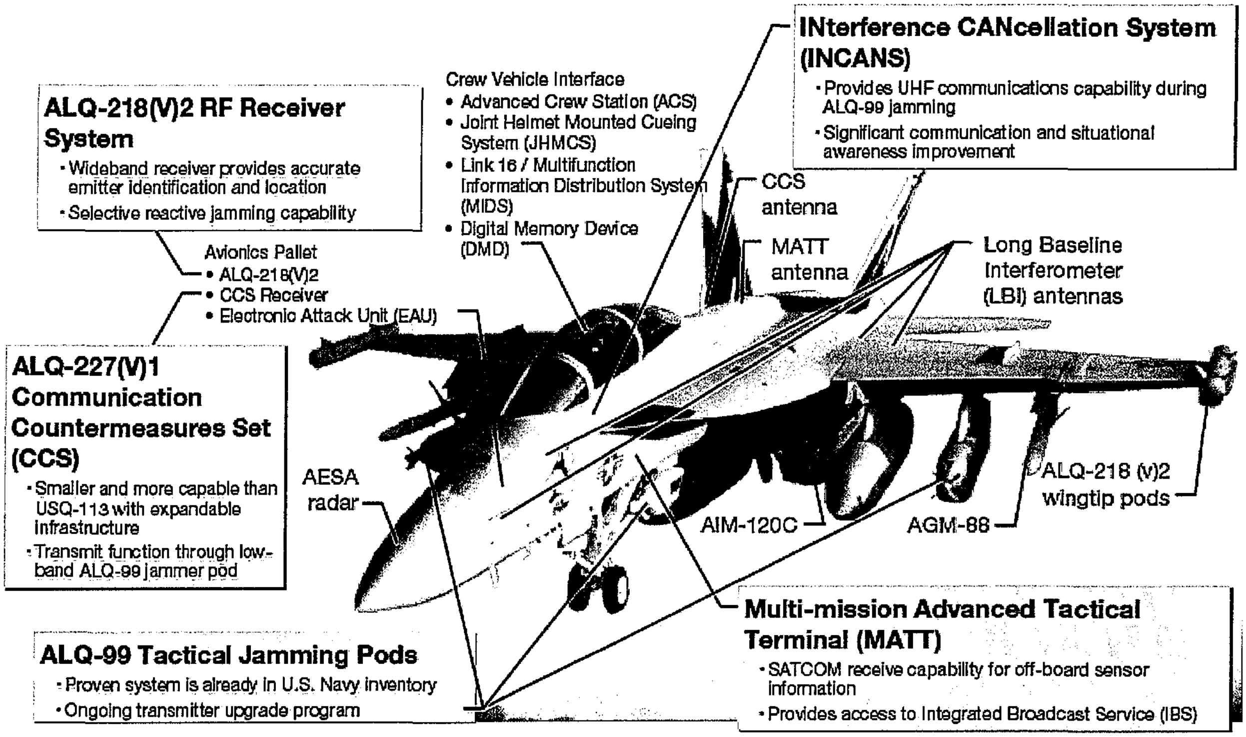
Boeing Integrated Defense Systems, Standoff Land Attack Missile Expanded Response SLAM-ER," The Boeing Company, http://www.boeing.com/defense-space/missiles/slam/index.htm.

Lockheed Martin, "Joint Air-to-Surface Standoff Missile (JASSM)," Lockheed Martin, http://www.lockheedmartin.com/products/jassm/index.html.

Raytheon Products & Services, "JSOW," Raytheon Company, http://www.raytheon.com/products/jsow/.

Raytheon Products & Services, "MALD," Raytheon Company, http://www.raytheon.com/products/mald/

APPENDIX F – EA-18G Growler Description



The EA-18G has potential to combine next-generation capabilities in geolocation, suppression, and destruction into a single platform. For geolocation requirements, the aircraft's ALQ-218 (Version 2) receivers bring new technology to the current ALQ-218 receiver system used in recent EA-6B upgrades. The ALQ-218(V2) addresses a capability gap in precision geolocation against air defense radars. Radar emissions are difficult to locate quickly with the precision necessary for attacks using modern PGMs. To accomplish precise threat geolocation, the ALQ-218(V2) is integrated with the aircraft's Active Electronically Scanned Array (AESA) radar. AESA's synthetic aperture mapping functions provide high-fidelity details about air defense threats that the ALQ-218(V2) geolocates.[82] Additionally, the EA-18G is a networked aircraft, capable of sharing its real-time information with other airborne assets. This is due to the capabilities of Link-16, the Multifunction Information Distribution System (MIDS) inherent in the EA-18G and and all F/A-18E/F aircraft. MIDS automatically exchanges battlefield

information – particularly locations of friendly and enemy aircraft, ships, ground threats, and ground forces – among all participating users in the network.

For non-kinetic weapons, the EA-18G integrates its ALQ-218(V2) with ALQ-99 jamming pods to enhance electronic attack capabilities and facilitate a selective-reactive jamming function to counter frequency agile radars. The Navy plans to replace EA-18G pods with next-generation jamming pods in the next ten years.[83] The aircraft also combines a new Communications Countermeasures System (CCS) with its jamming pods to locate and attack enemy communications.

A DEAD capability is the final goal for the EA-18G community that completes the sensor-to-shooter kill chain. The EA-18G's electronic attack and HARM suppression capabilities are planned to be supplemented with more lethal capabilities: AARGM and stand-off weapons (See Appendices C and E). The AARGM is being purchased for the F/A-18 family of aircraft; however, its addition to the EA-18G is dependant on the weapon's test schedule and is not "standard issue" for the aircraft's initial operating capability. Furthermore, stand-off weapons such as SLAM-ER, JSOW, JASSM, and MALD-J are planned to be integrated into the aircraft after fiscal year 2014; however, these additions are not currently funded.

Aside from its speed and weapons/stores loading capacity, the EA-18G brings some entirely new equipment and complexities to the AEA mission in terms of new on-board and off-board sensors. This includes the AESA air and ground search radar functions, combined with Advanced Medium Range Air to Air Missiles (AMRAAM) for self defense. AMRAAM allows EA-18Gs to operate without fighters attached for protection. An Interference Cancellation System (INCANS) allows the aircrew to communicate while jamming in certain low frequency ranges. For years, EA-6B aircrews have dealt with noise interference while jamming certain

radars, causing them to operate with severely limited situational awareness in a near "comm-out" environment. INCANS solves this potentially life-threatening problem; however, it essentially adds a sensor input of tactical communications while jamming. The Multi-mission Advanced Tactical Terminal (MATT) provides satellite communications capabilities and access to additional off-board sensors. Additionally, the network-centric capabilities of MIDS lays the foundation for the EA-18G to function as an EW "battle manager" in the future. Through MIDS connectivity with future Unmanned Aerial Vehicles (UAVs) carrying EW payloads, the EA-18G could coordinate UAVs that operate deep in the battlespace to perform high risk AEA functions.[84] These new functions enhance the capabilities of the aircraft, but similarly increase the complexity within the two-seat cockpit.

Although the EA-18G marks a generational leap for AEA aircraft, there are elements of DEAD missing from its initial operating capability in 2009. The most appropriate weapon that will immediately be added to the EA-18G is AARGM. Nonetheless, to complete the sensor-to-shooter kill chain the EA-18G must incorporate stand-off weapons such as SLAM-ER, JSOW, JASSM, and MALD-J, none of which are currently funded for the aircraft.

The EA-18G community must continue to highlight these stand-off weapon capabilities as critical future requirements. The capability that results will be an aircraft that shares network information to increase the capacity for all battlespace platforms and decision makers to receive real-time SIGINT and situational awareness. Similarly, multi-aircraft cooperative engagement can occur through electronic attack, ARMs, precision stand-off weapons, and UAS management.[85]

APPENDIX G – Relevant Tactical Fixed Wing Aircraft Dedicated to SEAD

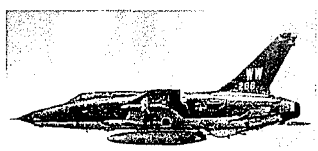
EF-10B Skynight – A modified F3D-2 two-seat night fighter, the EF-10B was equipped with electronic reconnaissance and countermeasures equipment in 1962. U.S. Marines flew the aircraft in Vietnam until its replacement by the EA-6A and later EA-6B.

SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes	No	Yes	No	No

EA3D-2 Skywarrior – The radar countermeasures version of the A-3D carrier based bomber. The EA-3D carried a crew of seven and specialized electronic reconnaissance and countermeasures equipment. It was introduced in 1956 and flew operationally until 1991.

SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes	No	Yes	No	No

F-105G Wild Weasel – The F-105G was a "hunter-killer" version of the two-seat F-105, intended for the suppression of SAM sites. The crew consisted of a pilot and electronic warfare officer, and typical armament included four Shrike missiles or two AGM-78 missiles. Production ended in 1965.



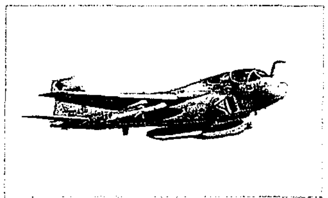
SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes (direction finding only)	No	No	Yes	Yes

EA-6A Intruder - First flown in 1963, this version of the two-seat A-6 Intruder was equipped primarily to support strike aircraft and ground forces by suppressing enemy electronic activity and obtaining tactical electronic intelligence within a combat area. Elements of the A-6As bombing/navigation system were deleted and replaced with equipment to detect, locate, classify, record, and jam enemy radars. Externally evident features included a receiver radome at the top of the tail fin and externally mounted jamming pods.

SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes	No	Yes	Yes	No

Quoted from: *Jane's All the World's Aircraft 2006-2007 (Jane's All the World's Aircraft).* (Alexandria: Jane's Information Group, 2006).

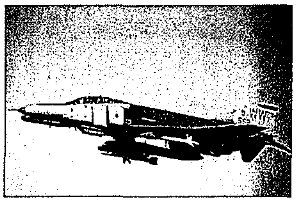
EA-6B Prowler – A four-seat advanced modification to the EA-6A, the EA-6B is the first U.S.



Navy aircraft specifically designed and built for the SEAD role. Originally unarmed, the aircraft was later modified to fire the AGM-88 HARM. The decision to retire the Air Force EF-111A and to assign all Department of Defense radar jamming missions to the Prowler adds to the significance of the EA-6B in joint warfare. With its jamming and HARM capability, the Prowler is a unique national asset that is deployed from land bases and aircraft carriers. Recent upgrades include the ALQ-218 tactical jamming receiver and Link 16. The EA-6B begins retirement from naval service in 2008, after a career that exceeds 35 years of deployments in support of USN, USMC, and USAF strike forces. The USMC will begin to retire the EA-6B in 2016, with a final retirement date of 2020.

SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes	No	Yes	Yes	No

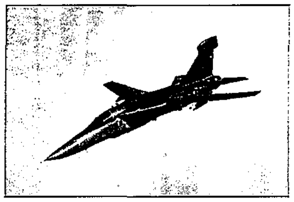
F-4G Advanced Wild Weasel - The F-4G "Advanced Wild Weasel," was an F-4E model



modified with sophisticated electronic warfare equipment in place of the internally mounted 20mm gun. The F-4G could carry more weapons than previous Wild Weasel aircraft and a greater variety of missiles as well as conventional bombs. The primary weapon of the F-4G, however, was the AGM-88 HARM. Other munitions included cluster bombs, and AIM-65 Maverick and air-to-air missiles.

SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes	No	No	Yes	Yes

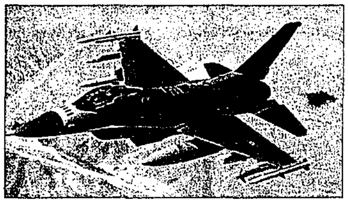
EF-111A Raven - This two-seat, converted F-111A included the same receivers and ALQ-99



tactical jamming system utilized by the EA-6B. Receivers were located in the tail fin radome, but the jamming pods were housed within the weapons bay. The EF-111As high speed allowed the aircraft to accompany strike aircraft in a direct escort role if desired, but remained unarmed throughout its service life. The EF-111A went into service in 1983, but was retired in 1998.

SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes	No	Yes	No	No

F-16CJ – This version of the F-16 was optimized for defense suppression missions. The aircraft carries a HARM targeting system with its associated sensor pod to give the F-16CJ a capability similar to the F-4G "Advanced Wild Weasel" which it replaced beginning in 1992. The most recent HTS upgrade is known as the R7 configuration, and offers a more precise emitter geolocation capability. The HTS R7 also offers the ability to utilize externally sourced targeting data acquired via Link 16.

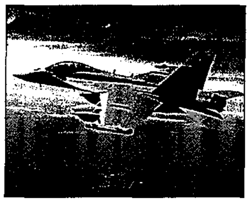


SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes	Yes (With R7 upgrade)	No	Yes	Yes

Panavia Tornado ECR - This is a Tornado strike aircraft modified to carry the HARM and an associated emitter location system to give the ECR a capability similar to the F-4G "Advanced Wild Weasel". The Tornado ECR is operated by the German and Italian Air Forces.

SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes	No	No	Yes	Yes (With AARGM purchase)

EA-18G Growler – The follow-on aircraft to the EA-6B, the EA-18G is adapted from the two-seat F/A-18F Super Hornet. The EA-18G is the first SEAD aircraft with potential capabilities to link SIGINT, precise geolocation, electronic attack, temporary suppression, and stand-off destruction of enemy air defenses (See Appendix F)



SIGINT	Precise Geolocation	EA	Temporary Suppression Weapons (ARM)	DEAD Weapons
Yes	Yes	Yes	Yes	Yes (With addition of AARGM and Stand-off Weapons)

APPENDIX H - Glossary of Acronyms and Terms

AAA – anti-aircraft artillery
AARGM – advanced anti-radiation missile
AESA – active electronically scanned array
ALCM – air launched cruise missile
ARM – anti-radiation missile
CCS – communications countermeasures set
DEAD – destruction of enemy air defense
DMO – distributed mission operation
DoD – department of defense
ELINT – electronic intelligence
EA – electronic attack
EW – electronic warfare
FIT – fleet introduction team
FRTC – fallon range training complex
GCI – ground controlled intercept
HARM – high speed anti-radiation missile
HTS – HARM targeting system
IADS – integrated air defense system
INCANS – interference cancellation system
ISR – intelligence, surveillance and reconnaissance
JASSM – joint air to surface stand off weapon
JSOW – joint stand off weapon
LD/HD – low density/high demand
MIDS – multifunctional information distribution system
MMW – millimeter wave
NSAWC – naval strike and air warfare center
NTTR – nellis tactical training range
PGM – precision guided munitions
SAM – surface to air missile
SIGINT – signals intelligence
SEAD – suppression of enemy air defense
SLAM-ER – stand off land attack missile – expanded response
TLAM – tomahawk land attack missile
TOFT – tactical operational flight trainer
TJR – tactical jamming receiver
TJS – tactical jamming system
UAV – unmanned aerial vehicle

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[2] Kenneth P. Werrell, *Archie to SAM: A Short Operational History of Ground Based Air Defense*, 2nd ed. (Maxwell AFB: Air University Press, 2005), 1.

[3] Since this mission can be either temporary or lethal in nature, current operators often make a distinction between SEAD and the destruction of enemy air defenses (DEAD). Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms* (Washington, D.C.: GPO, 2007), 523.

[4] Alfred Price, *Instruments of Darkness: The History of Electronic Warfare* (New York: Charles Scribner's Sons, 1978), 78.

[5] Price, *Instruments of Darkness*, 88.

[6] Other advances were made in the realm of air defense countermeasures, such as metal foil dropped from bombers and electronic countermeasure equipment within the bombers themselves; however, these tactics were primarily defensive in nature. As an afterthought to protect a single aircraft from an immediate threat, they were not designed to offensively target the enemy's air defense system for suppression or destruction. Price, *Instruments of Darkness*, 115 and 252-253.

[7] Alfred Price, *The History of U.S. Electronic Warfare Vol III* (Arlington, VA: The Association of Old Crows, 2000), 3-10.

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[18] Lieutenant Colonel James R. Brungess, *Setting the Context: Suppression of Enemy Air Defenses and Joint War Fighting in an Uncertain World* (Maxwell AFB: Air University Press, 1994), 5.

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[20] Hewitt, *Planting the Seeds of SEAD*, 15.

[21] This 1972 kill ratio was much lower than when it was first fielded in 1965, when the SA-2 claimed roughly one aircraft killed for every thirteen missiles launched. Price, *Instruments of Darkness*, 271.

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[23] Bert Kinzey, *The Fury of Desert Storm: The Air Campaign* (Pennsylvania: Tab Books, 1991), 15.

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[30] U.S. Department Of Defense, *Conduct of the Persian Gulf War: Final Report to Congress* (Washington, DC: GPO, 1992) 749-864.

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[33] Lambeth, *NATO's Air War for Kosovo,* 19.

[34] Lambeth, *NATO's Air War for Kosovo,* 102.

[35] Lambeth, *NATO's Air War for Kosovo,* 19-22.

[36] Lambeth, *NATO's Air War for Kosovo,* 103.

[37] Lambeth, *NATO's Air War for Kosovo,* 102, 104.

[38] Lambeth *NATO's Air War for Kosovo,* 106-108.

[39] David Fulghum, "NATO Unprepared for Electronic Combat," *Aviation Week & Space Technology*, vol. 150, iss. 19 (1999): 35.

[40] "One informed report observed that supporting F-16CJs were relatively ineffective in the reactive SEAD mode because the time required for them to detect an impending launch and get off a timely HARM shot to protect a striker invariably exceeded the flyout time of the SAM aimed at the targeted aircraft. As a result, whenever attacking fighters found themselves engaged by a SAM, they were pretty much on their own in defeating it." Lambeth, *NATO's Air War for Kosovo,* 107-108.

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